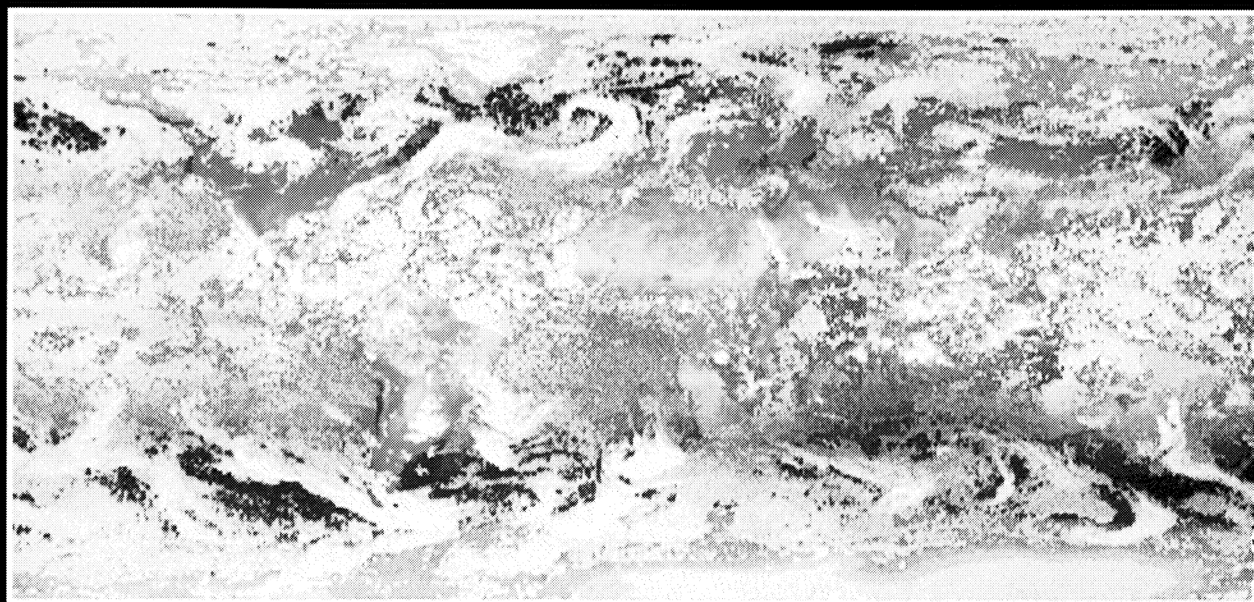
NASA's Mission To Planet Earth



Earth Observing System

On The Cover

Global composite image of infrared radiances measured by an international suite of weather satellites (METEOSAT-2, GOES-5, GOES-6, GMS-2, NOAA-7) on July 4, 1983 at the beginning of the International Satellite Cloud Climatology Project (ISCCP) for the World Climate Research Program (WCRP). Spatial resolution is about 50 km. The radiance values are assigned to one of four color tables. If clouds are present, a grey scale represents increasing cloud temperatures from warm (dark grey) to cold (white). If no clouds are present, the color table used to represent varying temperatures is decided by whether the particular location is land, water, or snow/ice.

INTRODUCTION

Space exploration has changed the way we view the Earth. Photographs from space show the limits of a world dominated by water and shielded from space by a thin layer of atmosphere. From this perspective, we see the Earth as a whole—the land, oceans, and atmosphere that provide our life-supporting environment.

Observations from space have provided extensive global views that allow us to study the Earth as a unified system. This systematic approach to Earth science will help us understand how local activities might produce effects on a worldwide or global scale. The goal is to understand relationships among atmosphere, land, and ocean processes on scales that range from chemical reactions to global climate change. To do this, Earth science needs an interdisciplinary approach that combines the classical disciplines of physics, chemistry, and biology.

Global studies require new and different tools. NASA will contribute to this effort through its Mission to Planet Earth (MTPE), which began in 1991 as a part of the U.S. Global Change Research Program. The MTPE focuses NASA's experience in planetary and space research on studies of the Earth. The central element in MTPE is the Earth Observing System (EOS). The EOS has three components: a series of Earth-observing satellites, an advanced computing system, and teams of scientists.

The objectives of the EOS are to:

- Establish an integrated, sustained, and comprehensive program to observe the Earth on a global scale;
- Conduct focused and exploratory studies to improve understanding of the physical, chemical, biological, and social processes that influence the Earth's climate;
- Develop models of the Earth system to integrate and predict climate changes; and
- Assess impacts of natural events and human activities on the Earth's climate.

The overriding goal of the EOS is to establish the scientific basis for informed policy decisions related to our influence on the global environment.

Scientists have known of and studied for decades many of the scientific issues described in the following sections. What is different is the challenge of unifying these studies to produce an understanding of the Earth as a single system. The EOS is the most ambitious single project dedicated to Earth system science and global climate change research. Building on existing and near-term missions, the EOS is supporting scientific studies and improving access to existing data that yield valuable information about the Earth and its climate system. In 1998, EOS leadership in climate change research will grow considerably by beginning a 15-year series of consistent, high-quality, global observations.

Studying Global Climate Change

The EOS focuses on the most critical issues in global climate change research. Seven key issues in global climate change were identified by the Intergovernmental Panel on Climate Change and the U.S. Global Change Research Program, an international scientific forum for coordinating research programs in global change. The key areas of scientific uncertainty identified are:

1. Sources and sinks of greenhouse gases, which affect predictions of their future concentrations and global warming;
2. Clouds and the Earth's radiation balance, which strongly influence the magnitude of climate change (for example, by cooling and/or warming of the Earth);
3. Oceans, which are the heat engine of global climate and influence the timing and patterns of climate change;
4. Land surface hydrology, which affects regional climate and water availability for agricultural and industrial development;
5. Polar ice sheets, which affect predictions of global sea level;
6. Ecological dynamics, such as vegetation patterns, biological diversity and carbon cycling, which are affected by or affect climate change; and
7. Volcanoes, which can add materials to the atmosphere that produce short-term effects similar to climate change.

Scientists based these priorities on the scientific uncertainty that exists, particularly as it affects the accuracy of climate predictions. The EOS will sponsor studies of the extent, causes, and regional consequences of global climate change by providing the means for observation, data and information management, research, and assessment. In the sections that follow, these seven key research areas of global climate change, as redefined in the priorities set by the EOS Investigator's Working Group, are discussed in terms of their known or potential importance in global climate change.

Radiation, Clouds, and Atmospheric Water

Earth's radiation budget is a vital part of the climate system. Absorption of solar radiation and heat lost to space determines, in large part, global temperatures and drives atmospheric winds and ocean currents. The amount of solar radiation absorbed by Earth depends largely on how much is reflected by clouds and aerosols. Clouds and certain active gases (called greenhouse gases) control the loss of heat from Earth.

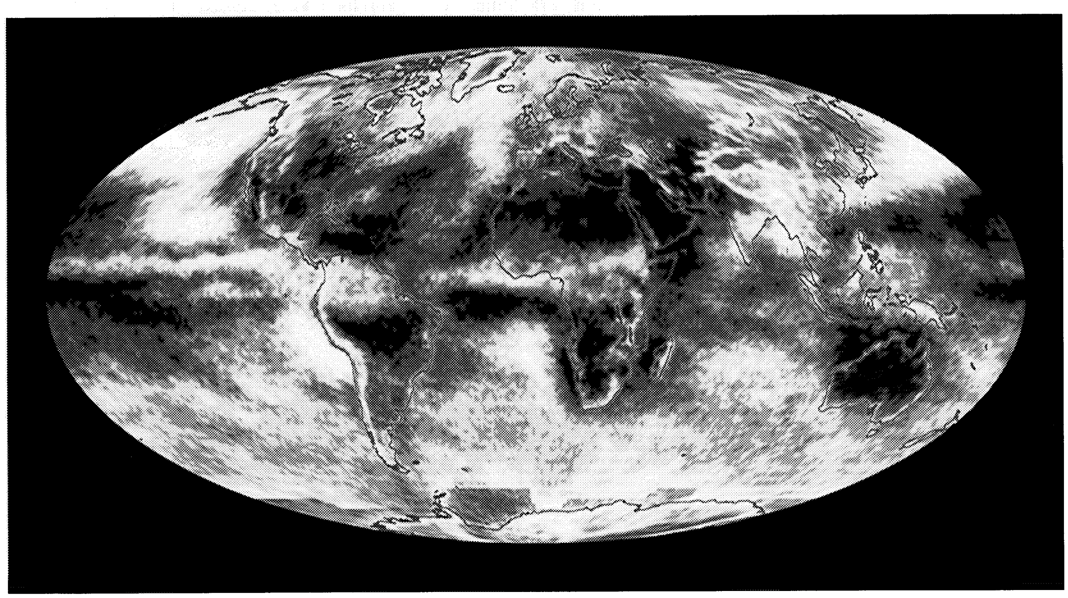
The most influential greenhouse gas is water vapor, controlled primarily by natural atmospheric processes. Human activities, such as burning fossil fuels, have increased concentrations of other greenhouse gases, including carbon dioxide. How increases in greenhouse gases have, and will, change the climate depends on their effects on natural radiation budget processes. Clouds have both warming and cooling effects that can change the radiation budget nearly as much as the warming from increased greenhouse gases. Climate modelers now regard clouds as the largest source of uncertainty in determining climate change associated with increases of greenhouse gases.

Clouds and water vapor also play a major role in the atmospheric hydrological cycle. We must understand

Radiation, Clouds and Atmospheric Water

Mean Surface Temperature for June 1988 (left): Average surface temperatures (increasing from blue-green-yellow-red).

Mean Effective Cloud Cover for June 1988 (below): Average cloud cover is greater than 60 percent for white areas, decreasing with darker shades to less than 10 percent.



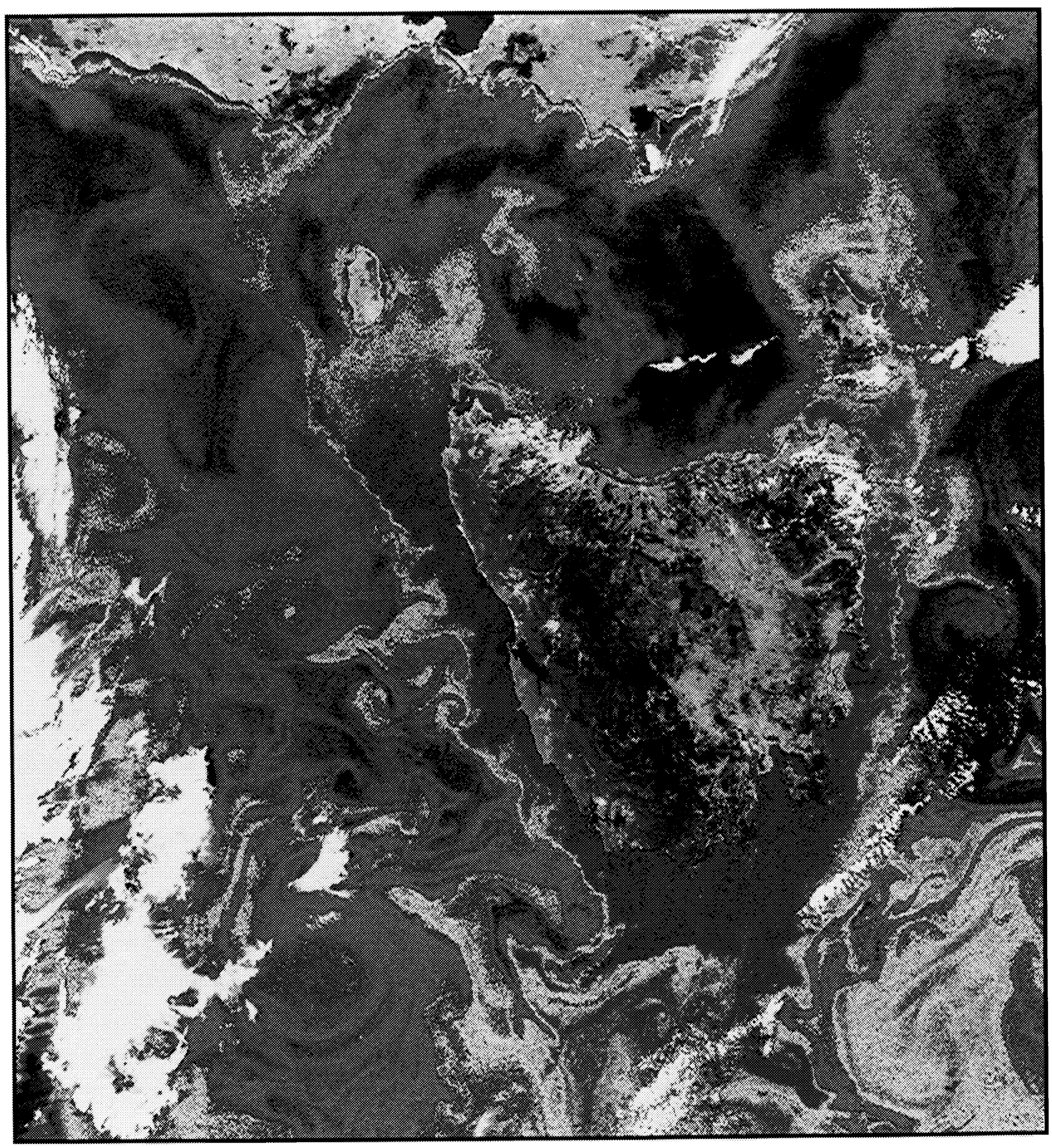
global hydrological cycles to determine future distributions of clouds and water vapor and their effects on radiation. Atmospheric water evaporates from land and oceans and returns to the surface through precipitation. Evaporation cools the Earth's surface, while condensation of water vapor into precipitation heats the atmosphere. These effects could be as important as radiation for atmospheric and oceanic motions. Patterns of precipitation on land influence natural vegetation, crops, drinking water, and floods.

The EOS will enable scientists to observe key parameters of Earth's radiation budget and atmospheric water cycle. Instruments will survey both large-scale, global features and fine-scale features such as particular cloud banks or land types. Today, NASA missions such as Earth's Radiation Budget Experiment (ERBE) and weather satellite services of many nations help EOS teams of atmospheric scientists, meteorologists, and hydrologists build advanced models for radiation, the water cycle, and climate prediction. These and other new predictive tools will improve our understanding of the role of clouds, radiation, and precipitation in global climate change, and allow us to assess their impacts on agricultural and industrial development.

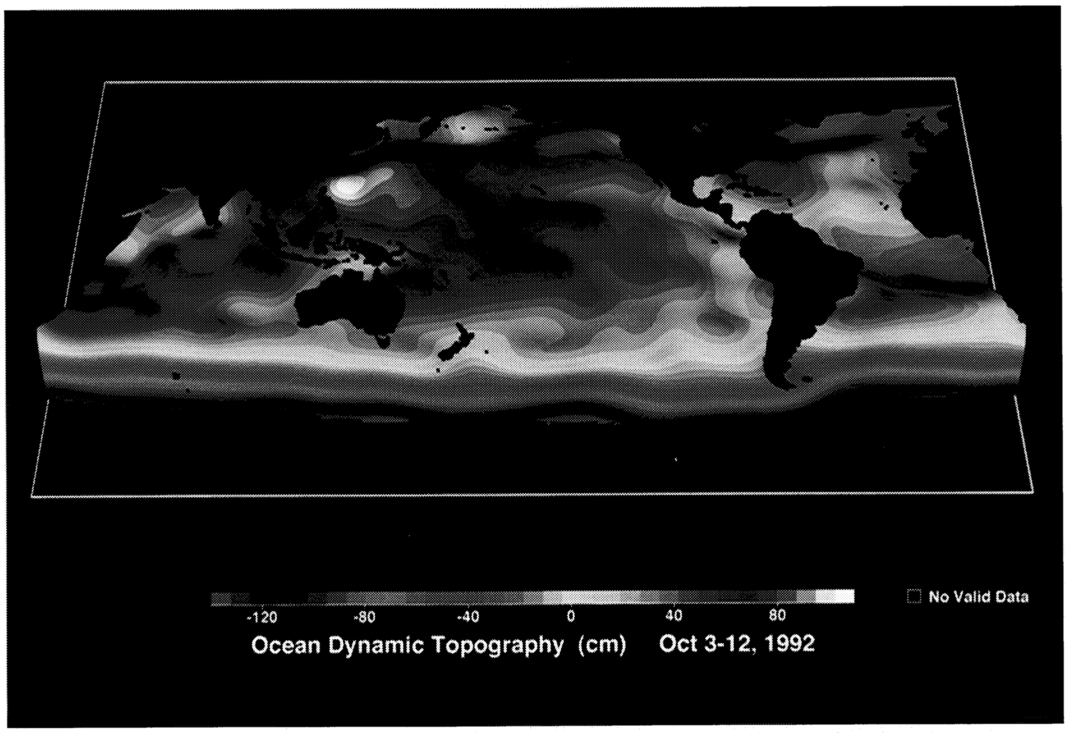
The Ocean

Covering more than 70 percent of the Earth and holding 97 percent of the water on our planet's surface, the ocean functions as a large reservoir of heat on the Earth's surface. The ocean and atmosphere exchange heat, momentum, and gases, and this interaction is the key to weather and climate patterns. Large-scale disruptions of weather patterns, such as those associated with El Niño, emphasize the importance of the ocean in our daily lives. We now know that the ocean controls such major changes as ice ages, and that large alterations occur in response to small changes in ocean conditions.

The ocean sustains a rich diversity of life, with biological activity rivaling that of land. Marine life plays its greatest role in the cycling of carbon, the base element for life and for key atmospheric greenhouse gases. Most biological production (the building of living matter from raw materials) in the ocean, as on land, occurs through photosynthesis. The main raw material for photosynthesis is dissolved carbon dioxide (CO_2). Increasing CO_2 concentrations, primarily caused by fossil-fuel burning, make it



The Ocean
Ocean Color around Tasmania: Phytoplankton pigment concentrations (increasing from blue-green-yellow-red) off the coasts of Tasmania and Australia.



THE OCEAN
Ocean Dynamic Topography: The speed and direction of ocean currents can be calculated from the highs and lows in the same way meteorologists estimate winds.

critical for us to understand how quickly CO_2 is dissolved, used, or stored in the oceans. Large amounts of carbon are recycled through food chains, some is released back to the atmosphere, and a large fraction settles to the bottom as dead organisms to be stored in sediments. Attempts to balance the Earth's carbon budgets will not succeed until we can measure accurately these stores and processes on a global basis.

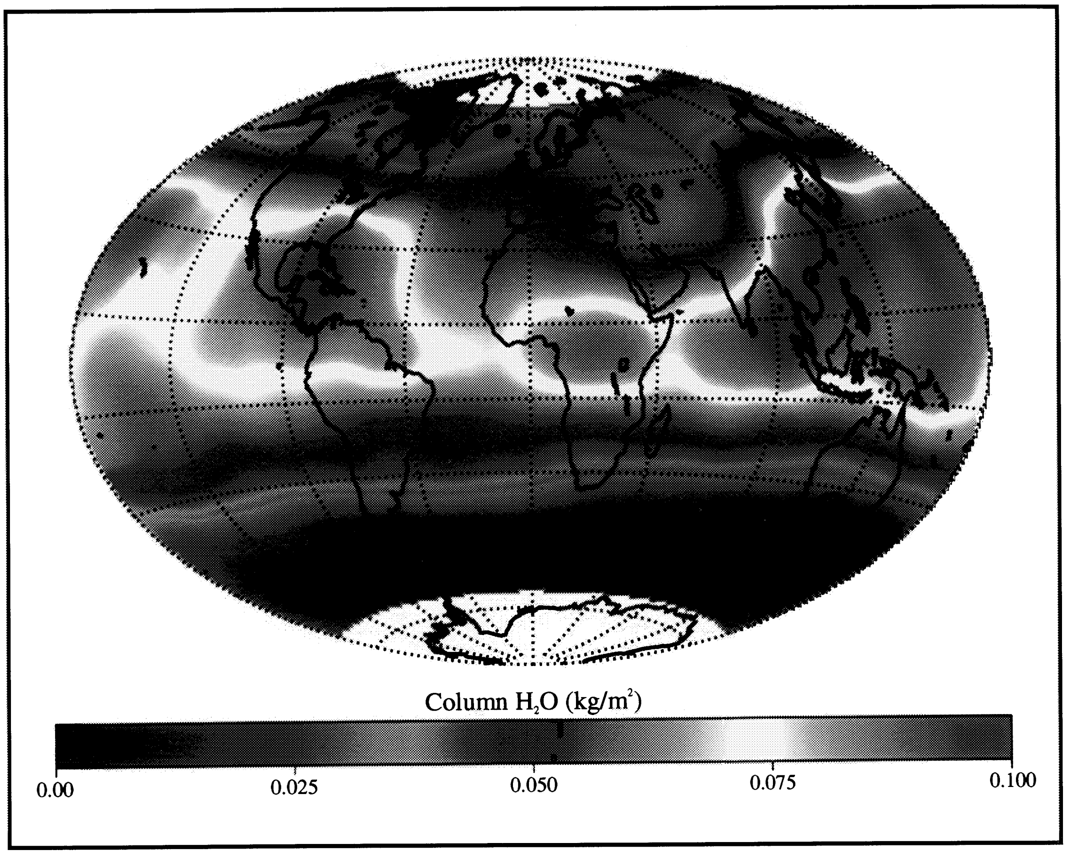
Researchers depend increasingly on information from satellites, ships, buoys, and computer models to gain a more complete picture of the ocean, and to enhance abilities to forecast ocean conditions akin to predicting daily weather.

Remote sensing from space is the only method that can supply consistent and routine observations covering the whole globe. The EOS will make space-based observations that provide measurements of temperature, surface elevation, wind speed and direction, sea-ice coverage, and phytoplankton pigments. Budget estimates for carbon and heat in the ocean also need EOS observations of solar radiation, clouds, and water vapor. The knowledge gained will help us to understand better the role of oceans in the global climate system, and to assess the impact of climate changes on resources such as fisheries and coastal lands and waters.

THE TROPOSPHERE: GREENHOUSE GASES

Scenarios for global warming rely primarily on the predicted increase in the "greenhouse effect" resulting from certain gases accumulating in the atmosphere because of human activities. Greenhouse gases include natural amounts of water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone. As the name greenhouse implies, the layer of atmosphere closest to Earth, the troposphere (from the surface to about 11 km), is the area in which greenhouse gases, dust, and clouds influence retention and transformation of solar energy.

THE TROPOSPHERE: GREENHOUSE GASES



SAGE II-Derived Water Vapor: Total water vapor between approximately 9 km and 16 km in the atmosphere during the northern summer (June through August, 1986–1988).

Natural cycles in the atmosphere, land, and ocean, as well as human activities, determine amounts of greenhouse gases in the troposphere.

Rapid growth in industry and agriculture during the past century contributed to unprecedented accumulations of certain greenhouse gases, including CO_2, CH_4, N_2O, and chlorofluorocarbons (CFCs). Computer models predict that if this buildup continues, temperatures could rise as much during the next century as during the 18,000 years since the last ice age. A climate change of this magnitude and speed could shift patterns of rainfall, winds, ocean currents, and regional weather, such as droughts and floods. Global warming could warm the ocean, and cause polar ice caps to melt. Sea levels would then rise, threatening coastal areas. History gives us few examples of the ability of humans and nature to adapt to such rapid change.

Scientists have identified some sources, sinks, and atmospheric transformations of greenhouse gases. By burning fossil fuels, we have introduced to the atmosphere large quantities of CO_2 that were formerly stored underground as oil, coal, and natural gas. Human production of CO_2 and CFCs is relatively well-known, and scientists have identified industrial and agricultural sources for CH_4 and N_2O. But many sources and sinks for greenhouse gases depend on natural cycles that are poorly understood. For example, useful estimates of amounts of CO_2 absorbed and released by land vegetation and oceans will require better understanding of biological activity and air-sea exchange.

The most significant and variable greenhouse gas is water vapor. Uncertainties about water cycle processes, such as evaporation and rainfall, limit our ability to predict long-term greenhouse effects. For example, it is not clear whether changes in the water cycle will speed up global warming by increasing water vapor concentrations, or counteract the greenhouse effect by screening the Earth with clouds.

The troposphere plays a critical role as a site for chemical reactions that determine the fate of greenhouse gases and other chemicals. Chemical oxidation in the troposphere limits the lifetime of many gases, such as methane. Chemical transformations in the troposphere also are critical to determine types and quantities of pollutants that will reach the stratosphere and contribute to reducing Earth's protective ozone layer.

Remote sensing by the EOS will measure all major greenhouse gases and many constituents involved in tropospheric chemistry. The EOS satellites will measure aerosols, water vapor, clouds, radiation, winds, and biological activity in the oceans and over the land. Integrating complex interactions among chemical, physical, biological, and human factors also will require field and laboratory studies, regular accounting of human factors, and improved computer models. Demand exists today for accurate assessments of greenhouse effects to develop policies that could constrain related human activities. The EOS will supply information needed to understand and predict climate changes from both natural and human causes. The EOS will play a vital role in enhancing knowledge and improving tools that world leaders need to make informed decisions.

Land Cover and the Water Cycle

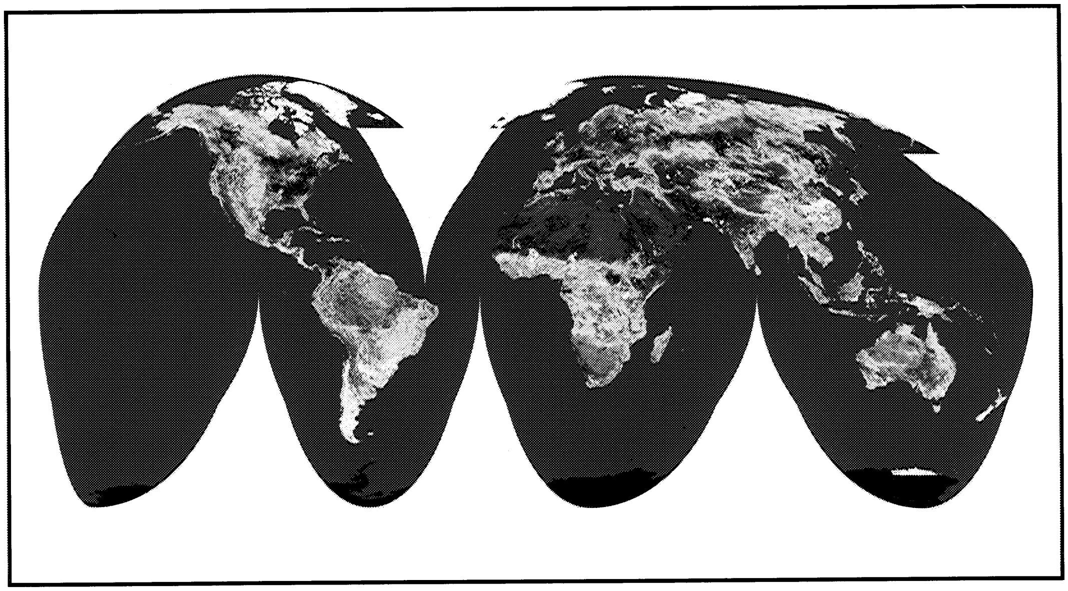
Human impacts on Earth are most visible in changes to the land. As our population has grown, we have altered the landscape to raise crops and animals, harvest forests, and build cities, roads, canals, and dams.

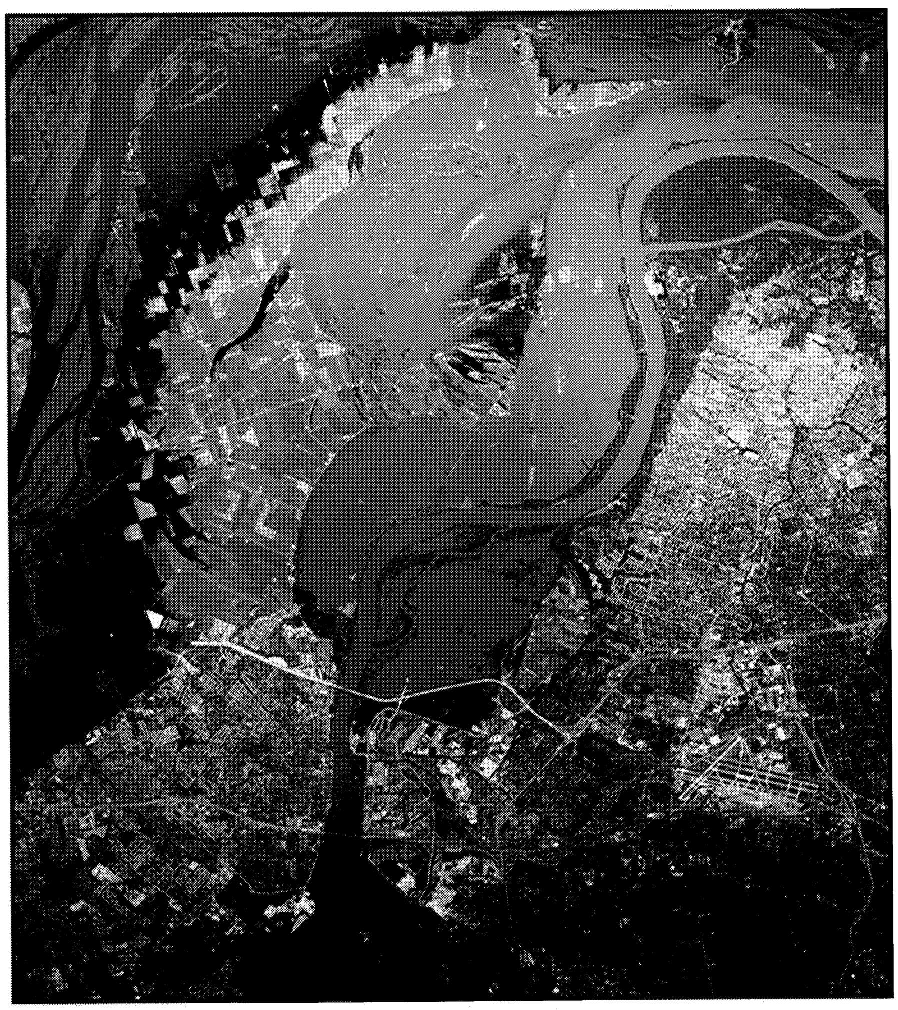
Land cover influences local weather and climate. Weather and climate, in turn, affect land cover, particularly patterns of vegetation and water distribution. The Earth's radiation budget depends partly on absorption and reflection from land surfaces, which differ greatly depending on soil or rock type, moisture content, vegetation type, and snow cover. Changes in vegetation cover can alter surface wind patterns and the exchange of moisture and heat with the air. These land-air interactions can affect local patterns of precipitation, water storage, and runoff that control the amount of water available for use in homes, agriculture, industry, and energy production.

Patterns of life have changed as land is converted from natural to human-dominated conditions. Biological processes engaged in the global carbon cycle have a significant but poorly quantified effect on greenhouse gas accumulation in the atmosphere. The greenhouse gases influenced by biological processes include carbon dioxide (CO_2), methane, and nitrous oxide. The most significant processes are those related to the storage and release of carbon. Plants, through photosynthesis, transform atmospheric CO_2 into organic matter. This process leads to a sink for CO_2, with carbon stored as living vegetation or as dead material in soils. Higher CO_2 concentrations can stimulate plant production and this carbon may end up stored by plants.

Land Cover and Water Cycle
Global Greenness Vegetation (right): 1-km AVHRR "greenness index" (increasing from brown-yellow-green, with white as clouds or snow) during the last week of June 1992.

Land Use and Hydrology (below): St. Louis and surrounding farmland at the confluence of the Mississippi River (upper left) and the Missouri River (center) at the peak of major floods in July 1993.





However, some land use changes may release this stored carbon into the atmosphere, thus changing land into a source of CO_2. For example, carbon is released to the atmosphere when forests are cleared and burned.

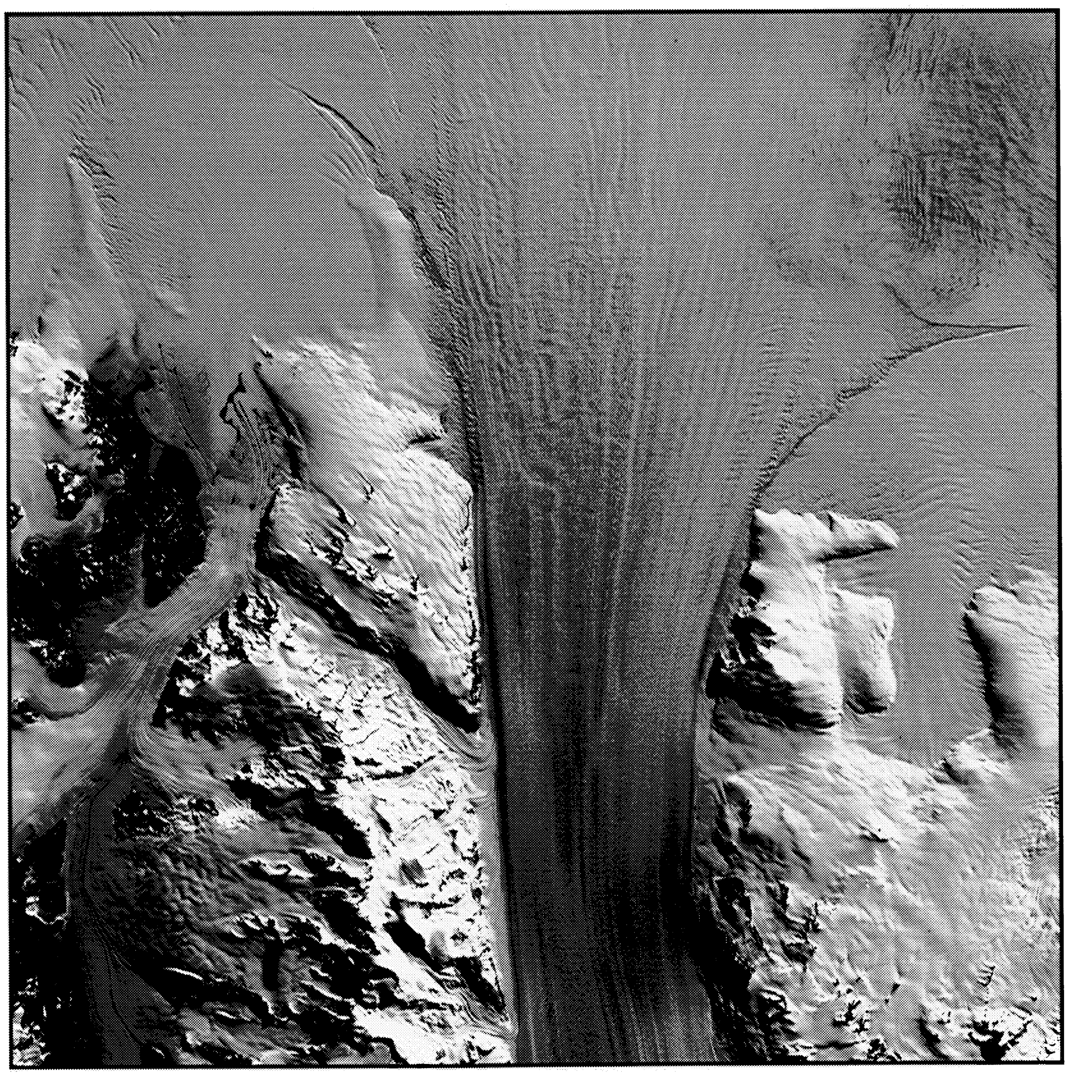
Space-based remote sensing provided by the EOS will contribute information on vegetation cover and its productivity, geological and mineralogical formations, soil moisture, and forest fires. In addition, detailed observations from the Landsat missions, which began in 1972, will continue to reveal changes in land use and land cover. Computer models of cycles of energy, water, and carbon, developed by EOS scientists, will further our understanding of how land processes affect, and are affected by, global climate change.

Polar Ice Sheets and Sea Level

One concern about global warming is that melting glaciers and ice sheets will cause sea level to rise, threatening coastal ecosystems, cities, and low-lying agricultural regions. The last century has seen a decrease in water stored in temperate mountain glaciers, accounting for part of the accompanying rise in sea level. Temperature increases also result in higher sea levels by causing the oceans to expand. However, we do not know whether large polar ice sheets are growing or shrinking, or how they will respond to climate change.

Satellite laser and radar altimeters in the EOS will measure changes in surface heights of ice sheets and oceans to determine changes in the size of ice sheets. Scientists use this information, models of ice dynamics, and observations of temperatures and precipitation in polar regions to predict changes in the ice volume and sea level.

Studies of ice sheet dynamics will use high-resolution data from microwave synthetic aperture radar (SAR) instruments on European, Japanese, and Canadian satellites. The U.S. Landsat missions have collected high-resolution images since 1972 and will continue through the EOS era to build a detailed time record. Local measurements of sea level, which date back to the last century for some ports, help validate observations from satellite altimeters such as the Ocean Topography Experiment (TOPEX/POSEIDON) satellite mission begun in 1992. The goal of these efforts is to understand links between climate, glaciers, and sea level, and to assess environmental, economic, and social impacts for coastal regions.

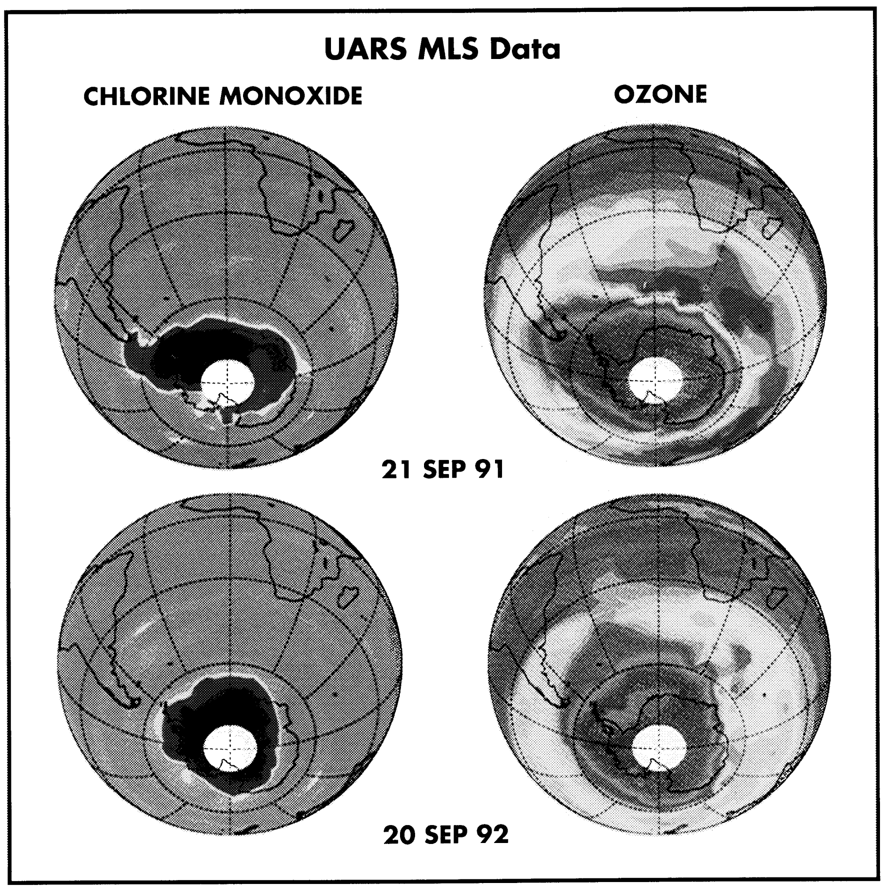


POLAR ICE
Byrd Glacier: High-resolution image of the Byrd Glacier, Antarctica as it flows into the Ross Ice Shelf.

THE STRATOSPHERE: OZONE CHEMISTRY
The "Ozone Hole:" Concentrations of ozone and chlorine monoxide (a product of ozone destruction) in the stratosphere over Antarctica during the peak of the "ozone hole" season in 1991 and 1992 (increasing from light pink-blue-green-yellow-red-hot pink-dark purple).

THE STRATOSPHERE: OZONE CHEMISTRY

One of the most striking and well-publicized examples of recent global change is the Antarctic ozone hole that develops each spring. This "hole" is actually a decrease in the amount of ozone in the stratosphere, the layer of the atmosphere approximately 11 to 48 kilometers above the Earth's surface. Since the mid-1970s, the Antarctic ozone hole has grown in severity and extent, and the stratospheric ozone layer has thinned over much of the globe. Scientists relate this trend to the release of certain man-made chemicals, such as the chlorofluorocarbons used in refrigerators and air-conditioners, which break down in the stratosphere to yield products that destroy ozone.



The fate of stratospheric ozone represents a prime example of the global reach of human activities.

The ozone layer protects life on Earth from dangerous forms of solar ultraviolet (UV) radiation. Thinning of the ozone layer can increase UV radiation reaching the Earth's surface. Increased exposure to UV radiation harms many organisms on land and near the ocean surface. In humans, UV exposure increases the occurrence of skin cancer and cataracts.

Transfers of chemicals and radiation between the stratosphere and the troposphere influence many atmospheric processes, including the greenhouse effect and ozone destruction. Whereas greenhouse gases in the troposphere warm the air near the Earth's surface, the same gases reaching the stratosphere can cool the upper atmosphere by reflecting heat into space. This heating and cooling will alter both the structure of the atmosphere and the speed of chemical reactions taking place.

Focused research programs and remote-sensing observations in the last 15 years have improved our understanding of ozone chemistry. Ground measurements that first revealed the Antarctic ozone hole led to studies of atmospheric chemistry in polar regions using ground, aircraft, and balloon observations, along with modeling experiments. Total Ozone Mapping Spectrometer (TOMS) instruments on several satellites have collected data worldwide since 1978. These studies demonstrated the role of human-made chemicals in ozone depletion. Policy responses include the Montreal Protocol, an international phase-out of the most dangerous pollutants that lead to ozone destruction.

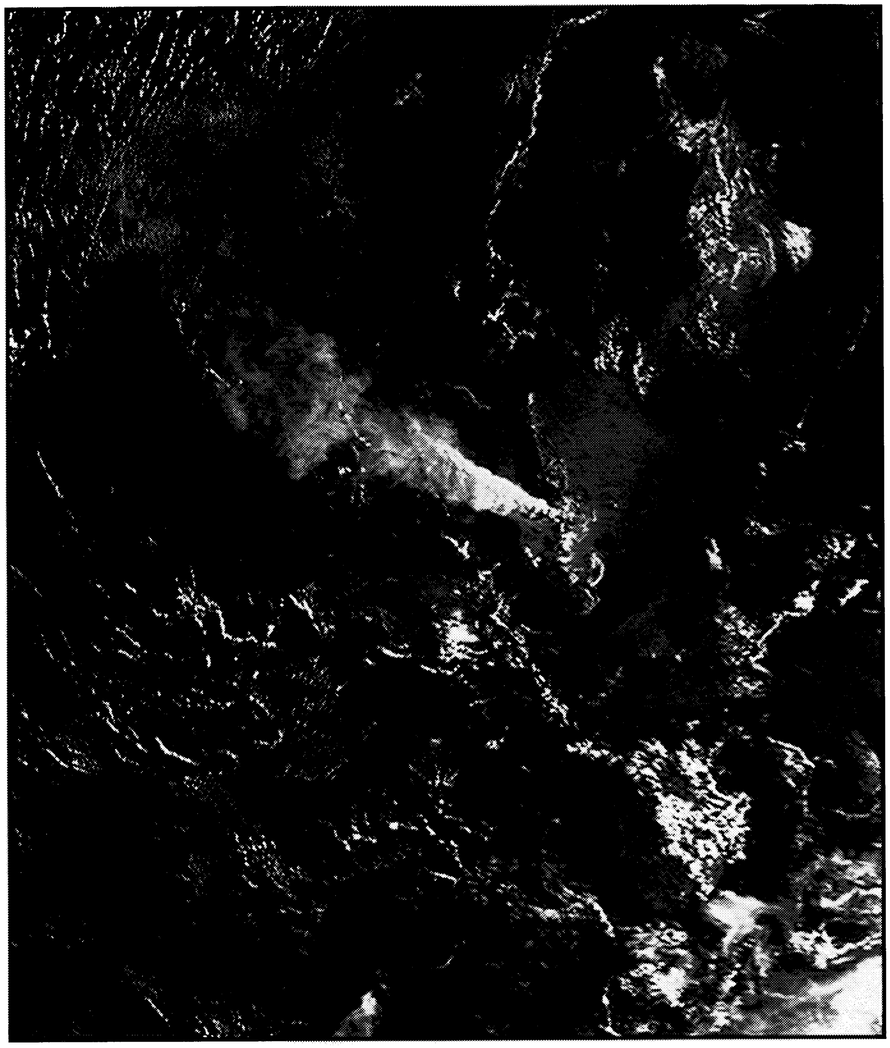
The latest remote-sensing mission to study stratospheric chemistry began in 1991 with NASA's Upper Atmosphere Research Satellite (UARS). The EOS will continue to monitor ozone and other elements of stratospheric chemistry. These investigations will improve the accuracy of observations and model predictions of stratospheric conditions, and help assess past and future policy decisions.

VOLCANOES

Since the eruption of Mount Tambora in 1815 in New Guinea, the scientific community has recognized that volcanoes can influence weather conditions on a global scale. Volcanic eruptions inject large quantities of dust, gas, and aerosols into the atmosphere. Dust particles settle rapidly, but aerosols and gases can stay aloft for years if they reach the stratosphere. These materials absorb and reflect solar radiation in the atmosphere, which causes cooling at the Earth's surface. This cooling can temporarily offset global warming due to other climatic effects.

Thus, volcanoes are important to global climate change research because eruptions cause natural variations in the climate record. For example, aerosols from the 1991 eruption of Mount Pinatubo in the Philippines caused a decrease in global temperature through 1993. Volcanoes also serve as natural tests for atmospheric circulation models by injecting ash into the atmosphere that can then be tracked via satellites, as with the Mt. Spurr (Alaska) eruption in 1992.

The EOS will provide scientists with the means to study both the extent of volcanic activity and inputs to the atmosphere. Remote sensing is used to observe swelling of volcanoes or addition of new lava flows. Surface temperatures can be observed from space to monitor activity in volcanic craters. Scientists will develop methods to model and predict hazardous activity. Volcanic eruptions will be monitored from space by remote observations of atmospheric gases, aerosols, and clouds. The major contribution to climate change research will be to evaluate the dramatic effects of volcanic eruptions on atmospheric chemistry and radiation budgets. This effort is critical for predicting the impacts of volcanoes on short- and long-term global climate change.



VOLCANOES
Eruption Plumes and Volcanic Clouds:
The eruption of Mount Pinatubo in the Philippines on July 5, 1991.

The Earth Observing System: How NASA Will Support Studies of Global Climate Change

The EOS supports three main activities: scientific investigation, space-based observation, and data management. Planning and building the technical and human resources for the EOS require close collaboration among engineers, computer scientists, and Earth scientists. The first pieces of the EOS were established in 1990 with the selection of proposals to form science teams and develop instruments. In 1991, the EOS Data and Information System (EOSDIS) began building on a base of selected Earth science data centers.

Thus the EOS is well underway. EOS science investigations are making significant contributions to our knowledge of the Earth and its climate system, today. Individually and as teams, these scientists are forging interdisciplinary collaborations and training the next generation of Earth system scientists. The scientific investigators and general Earth science community currently make use of new facilities and improved access to existing data provided by the EOSDIS. While the first EOS satellite will not launch before 1998, instrument development efforts have produced simulator instruments for testing from aircraft. Data from these simulators are used to support current EOS science investigations and to develop new uses for the unique types and quality of satellite data that the EOS will provide.

Research and Assessment: EOS Science Investigations

In 1990, NASA confirmed 29 teams of scientists as part of the EOS Interdisciplinary Science Investigations. These investigations will focus on: 1) obtaining understanding of key Earth system processes; 2) developing predictive numerical models; 3) increasing use and utility of existing satellite data; and 4) preparing for use of new types of data expected from new instruments. Scientists leading these investigations employ the help of graduate students, post-doctoral research fellows, and technicians for a total exceeding 800 researchers. The governments of Australia, Brazil, Canada, France, Japan, and the United Kingdom support eight of these research teams.

In addition, each EOS instrument and each EOSDIS data center has science teams or a science working group. EOS Instrument Science Teams work on instrument design, development, calibration, and data applications. EOSDIS scientists help anticipate and meet the computing and data needs of EOS scientists.

The NASA Global Change Graduate Student Fellowship Program began in 1990 to ensure a pool of highly qualified Earth scientists who can use data generated during the EOS mission. This program supports students pursuing their doctorates in Earth system science. A total of 221 fellows was selected from 1,365 applications over the first four years of the program. Forty percent were women, and 21 percent represent 21 countries outside the U.S. These students have conducted research at 66 institutions across the U.S. NASA will grant approximately 50 new awards each year to maintain support for 150 to 200 students through the lifetime of the EOS program. The program also stresses:

- Developing teaching materials for K-12 and undergraduate and graduate levels;
- Developing introductory and advanced-level courses in Earth System Science concepts; and
- Training teachers/educators through summer schools and short-courses.

EOS Data and Information System (EOSDIS)

The EOS will support researchers by developing a computing and communication system to receive, process, store, and distribute sizable amounts of data and information about the Earth. One general goal of data and information systems is to remove the need for each user to have detailed knowledge of remote-sensing instruments and methods. Along with scientific research, the user community for EOSDIS-provided information and services could include those interested in commercial applications, education, resource inventories and planning, policy decisions, and disaster assessment.

Teams of scientists will bear responsibility for ensuring the quality of EOS data products, subject to the peer review common in scientific research. The EOSDIS currently archives and distributes data from past and current satellite missions. Projects to improve availability and quality of existing data sets, called Pathfinders, are providing information with recognized value to global climate change research. Pathfinder projects and ongoing satellite missions will serve as the first step for scientists and EOSDIS developers.

The technical goal of the EOSDIS is to develop a system that will evolve and grow to allow increasingly sophisticated uses and analyses of data and information. For a system as large and complex as the EOS, an inadequate computing system could limit or discourage the efficient use of data and information. Given the international nature of the EOS program, data and information must flow easily worldwide.

The EOSDIS components consist of a network of data centers and facilities for instrument control, data storage, computing and communications. These components of EOSDIS will resemble a single entity to users. Distributed Active Archive Centers (DAACs) will bear responsibility for product generation, information management, and data and information archive and distribution. The data centers selected for the EOSDIS each focus on a particular type of data or scientific field. Users will access the EOSDIS from external computer networks such as the U.S. National Research and Education Network (NREN).

Fulfilling user needs will require an EOSDIS that can evolve constantly to incorporate new computer technology. The EOSDIS version due in 1994 will introduce common services for information management, data archive and distribution through the data centers. At launch of the first EOS satellite in 1998, EOSDIS will be fully integrated, with all major functions available. The EOSDIS will continue to evolve throughout the EOS mission in response to requirements for global change research, mission operations, and broad user access.

EOS Observations: Instruments and Spacecraft

The most visible part of the EOS will be the series of satellites carrying advanced remote-sensing instruments. These small- to intermediate-size satellites, each carrying one to six instruments, will be launched beginning in 1998. The enclosed fact sheet describes the EOS satellites and their measurement objectives. Replacement satellites, launched every three to five years, will provide a minimum of 15 years of continuous global observations.

Most of the satellites will orbit over the polar regions and synchronous with the sun to get consistent, global coverage. The EOS-AEROSOL satellite series, an exception, will fly in a different orbit relative to the sun. This orbit will provide a second view of atmospheric aerosols compared with identical instruments on EOS-CHEMISTRY. EOS-COLOR will make a single flight needed to continue the series of afternoon ocean color measurements between the SeaWiFS (Sea-viewing Wide Field-of-view Sensor) mission to begin in 1994, and the first EOS-PM mission in 2000.

The EOS will involve 23 different instruments. The United States and Japan will collaborate to place the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on the EOS AM-1 satellite and to place SeaWinds on Japan's Advanced Earth Observing System (ADEOS) satellite series. The U.S. and the United Kingdom together will develop and build the High-Resolution Dynamics Limb Sounder (HIRDLS). The EOS will carry instruments from Canada (Measurements of Pollution in the Troposphere, or MOPITT), France (Doppler Orbitography and Radiopositioning Integrated by Satellite [DORIS], and Solid-State Altimeter, or SSALT), and Europe's Multifrequency Imaging Microwave Radiometer (MIMR). Within the U.S., NASA will work with the National Oceanic and Atmospheric Administration (NOAA) to develop the Advanced Microwave Sounding Unit (AMSU) instrument. In addition, NASA consults with the remote-sensing programs of other U.S. agencies and international partner space agencies to coordinate measurements that complement those of the EOS.

A National and International Effort

The Earth Observing System is the core program of NASA's Mission to Planet Earth initiative. It represents, however, only part of the efforts underway in the U.S. and other countries to conduct long-term observations and scientific studies of global climate change. Other components of NASA's Mission to Planet Earth include:

- Satellite missions leading up to, and complementing, the EOS;
- Continuations of successful small satellite programs;
- Observation from the Space Shuttle; and
- Remote sensing from aircraft.

Several small satellite programs are underway or planned. The TOMS instruments that have been monitoring global ozone levels since 1978 are upgraded and replaced periodically. The Italian LAGEOS-II (Laser Geodynamics Satellite II) was launched by NASA in 1992 to aid measurements of Earth's surface movements and gravity field. The SeaWiFS mission will launch in 1994, resuming ocean color (phytoplankton) measurements made from 1978 to 1986.

Mission to Planet Earth includes larger, multi-instrument satellites. The UARS has measured atmospheric chemistry and radiation since 1991. The joint U.S./France mission, TOPEX/POSEIDON, was launched in 1992 to study ocean currents. Japan's ADEOS, scheduled for launch in 1996, will carry NASA's TOMS to monitor ozone and NSCAT to measure wind speed and direction over the oceans. The Tropical Rainfall Measuring Mission (TRMM) is set for launch in 1997 as a joint U.S./Japan mission to help understand the role of tropical regions on Earth's climate.

The Space Shuttle provides short demonstration flights for new instruments, such as the multifrequency Shuttle Imaging Radar-C (SIR-C), which will be capable of viewing land under all weather conditions. The Shuttle also carries well-calibrated research instruments for detailed studies from space, as with the annual flights of the Atmospheric Laboratory for Applications and Science (ATLAS), which has focused on atmospheric chemistry and radiation since 1992. Aircraft missions serve a similar role, providing tests and validation of instruments simulating those used in space.

The U.S. Global Change Research Program coordinates and guides the efforts of federal agencies. These agencies include NASA, the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation, the Environmental Protection Agency, the U.S. Geological Survey, and the Departments of Energy, Defense, and Agriculture. Successful remote-sensing missions outside NASA include: NOAA's operational weather satellites that provide global data for radiation, clouds, water vapor, sea surface temperatures, and vegetation; the Defense Meteorological Satellite Program that provides information on sea ice, atmospheric water, and land surface characteristics; and the Landsat program that provides detailed images of land. All U.S. agencies listed above have extensive data sets based on ground, ship, and aircraft measurements that complement satellite observations.

NASA encourages the widest possible participation from international partners in the development and implementation of its Mission to Planet Earth. For instance, Europe, Canada, and Japan have programs complementary to the EOS that together comprise the International Earth Observing System (IEOS). The Committee on Earth Observations Satellites (CEOS) aids coordination at the international level. Members of the CEOS include agencies of Australia, Brazil, Canada, France, Germany, India, Italy, Japan, Russia, Sweden, the United Kingdom, and the U.S. (through NASA and NOAA). International research programs have initiated global studies and promoted scientific collaborations and interdisciplinary research. Examples include the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), and the United Nations Environment Programme (UNEP).

Understanding the Earth System

A great need exists for information that can help us evaluate our options to sustain the environmental conditions that have nurtured life on Earth. Mission to Planet Earth and the EOS will supply information needed to understand and predict climate changes from both natural and human causes. This information will allow for policy decisions that balance human needs and desires with protection of the Earth's environment.

Global change research will have practical benefits and will allow us to leave a legacy of responsibility. The practical benefits will include improvements in our ability to forecast climate, manage natural resources, protect public health, and plan for crops, forests, fisheries, wildlife, and human needs. The EOS will offer one means of fulfilling our moral and civic responsibilities as stewards of our home planet to future generations.

Image Credits

1. Mean surface temperatures derived from a combination of data from the Microwave Sounding Unit (MSU) and the High-Resolution Infrared Sounder (HIRS 2). Image courtesy of JPL and GSFC. 2. Mean effective cloud cover derived from a combination of data from HIRS 2 and MSU. Image courtesy of JPL and GSFC. 3. Ocean dynamic topography measurements taken by the radar altimeter on the TOPEX/POSEIDON satellite in October 1992. Image courtesy of JPL. 4. Phytoplankton pigment concentration color observed in November 1981 by the Coastal Zone Color Scanner (CZCS) on the Nimbus-7 satellite. Image courtesy of GSFC. 5. Water vapor as measured by the Stratospheric Aerosol and Gas Experiment (SAGE II) instrument on NASA's Earth Radiation Budget Satellite. Image courtesy of LaRC. 6. Vegetation observed by the Advanced Very High Resolution Radiometer (AVHRR) on NOAA weather satellites during the last week of June 1992. Image courtesy of USGS/EROS Data Center. 7. Mississippi River and Missouri River flood visible from the aircraft version of the Moderate Resolution Imaging Spectroradiometer (MODIS) to be deployed on EOS satellites. Image courtesy of GSFC. 8. Byrd Glacier high-resolution image from the Landsat satellite. Image courtesy of USGS. 9. Southern Hemisphere ozone and chlorine monoxide concentrations measured by the Microwave Limb Sounder (MLS) on NASA's Upper Atmosphere Research Satellite (UARS); MLS also will be deployed in the EOS. 10. Mt. Pinatubo as viewed by the AVHRR on a NOAA weather satellite. Image courtesy of NOAA. On the cover, world cloud cover pattern and surface temperature on October 15, 1983, assembled from the U.S. (NOAA), Europe (METEOSAT), and Japan (GMS) weather satellites. Image courtesy of GISS.

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EOS Satellites and Mission Objectives

EOS Satellites (first launch year)	Key Measurements
EOS-AM Series (1998) Morning Crossing	Clouds, radiation, and aerosols Surface temperatures of land and ocean Vegetation and ocean phytoplankton Global biological productivity Chemistry of the troposphere
EOS-COLOR (1998)	Ocean phytoplankton and biological production (afternoon)
EOS-AEROSOL SERIES (2000)	Aerosols Chemistry of the stratosphere
EOS-PM Series (2000) Afternoon Crossing	Clouds, radiation, and aerosols Precipitation and humidity Snow cover and sea ice Surface temperatures of land and ocean Vegetation and ocean phytoplankton Global biological productivity
EOS-ALTIMETRY SERIES (2002)	Ocean circulation and sea level Ice sheet elevation Land surface elevation Cloud layering
EOS-CHEMISTRY SERIES (2002)	Chemistry of the troposphere Chemistry of the stratosphere Aerosols Solar radiation

EOS Instruments and Satellites

Acronym	Full Instrument Name	Satellite Series	Oversight
ACRIM	Active Cavity Radiometer Irradiance Monitor	EOS-CHEM	NASA/Jet Propulsion Laboratory, California
AIRS	Atmospheric Infrared Sounder	EOS-PM	NASA/Jet Propulsion Laboratory, California
AMSU	Advanced Microwave Sounding Unit	EOS-PM	National Oceanic and Atmospheric Administration (U.S.)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer	EOS-AM-1	Japan and NASA/Jet Propulsion Laboratory, California
CERES	Clouds and Earth's Radiant Energy System	EOS-AM; EOS-PM	NASA/Langley Research Center, Virginia
COLOR	Ocean Color Instrument	EOS-COLOR	NASA/Goddard Space Flight Center, Maryland
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite	EOS-ALT	Centre National d'Etudes Spatiales (France)
EOSP	Earth Observing Scanning Polarimeter	EOS-AM-2,3	NASA/Goddard Institute for Space Studies, New York
GLAS	Geoscience Laser Altimetry System	EOS-ALT	University of Texas
HIRDLS	High-Resolution Dynamics Limb Sounder	EOS-CHEM	United Kingdom and National Center for Atmospheric Research, Colorado
MHS	Microwave Humidity Sounder	EOS-PM	European Organization for the Exploitation of Meteorological Satellites
MIMR	Multifrequency Imaging Microwave Radiometer	EOS-PM	European Space Agency
MISR	Multi-angle Imaging Spectro-Radiometer	EOS-AM	NASA/Jet Propulsion Laboratory, California
MLS	Microwave Limb Sounder	EOS-CHEM	NASA/Jet Propulsion Laboratory, California
MODIS	Moderate-Resolution Imaging Spectrometer	EOS-AM; EOS-PM	NASA/Goddard Space Flight Center, Maryland
MOPITT	Measurements of Pollution in the Troposphere	EOS-AM-1,2	Canadian Space Agency
SeaWinds	Scatterometer	ADEOS II (Japan)	NASA/Jet Propulsion Laboratory, California
SAGE III	Stratospheric Aerosol and Gas Experiment, third generation	EOS-CHEM; EOS-AERO	NASA/Langley Research Center, Virginia
SOLSTICE II	Solar Stellar Irradiance Comparison Experiment, second generation	EOS-CHEM	University of Colorado
SSALT	Solid State Altimeter	EOS-ALT	Centre National d'Etudes Spatiales (France)
TES	Tropospheric Emission Spectrometer	EOS-AM-2,3	NASA/Jet Propulsion Laboratory, California
TMR	TOPEX Microwave Radiometer	EOS-ALT	NASA/Jet Propulsion Laboratory, California

EOS Data Centers

Name	Area of Interest	Oversight	Location
ASF Alaska SAR Facility	Synthetic Aperture Radar (SAR) for ice, snow and sea surface	University of Alaska	Fairbanks, Alaska
EDC Earth Resources Observation System (EROS) Data Center	Land features and processes	U.S. Geological Survey	Sioux Falls, South Dakota
GSFC Goddard Space Flight Center	Atmospheric physics and meteorology, stratospheric chemistry, ocean biology, and geophysics	NASA	Greenbelt, Maryland
JPL Jet Propulsion Laboratory	Physical oceanography	NASA	Pasadena, California
LaRC Langley Research Center	Clouds, radiation, aerosols, and tropospheric chemistry	NASA	Hampton, Virginia
MSFC Marshall Space Flight Center	Hydrologic cycle	NASA	Huntsville, Alabama
NSIDC National Snow and Ice Data Center	Sea ice and snow cover	University of Colorado	Boulder, Colorado
ORNL Oak Ridge National Laboratory	Trace gas fluxes	Department of Energy	Oak Ridge, Tennessee
CIESIN Consortium for International Earth Science Information Network	Human dimensions of global change and policymaking applications	Environmental Research Institute of Michigan	Saginaw, Michigan

EOS Interdisciplinary Science Investigations	Principal Investigators	Home Institutions
Coupled Atmosphere-Ocean Processes and Primary Production in the Southern Ocean	Mark Abbott	Oregon State University
Global Water Cycle: Extension Across the Earth Sciences	Eric Barron	Pennsylvania State University
Long-term Monitoring of the Amazon Ecosystems through EOS: from Patterns to Processes	Getulio Batista and Jeffrey Richey	Instituto Nacional de Pesquisas Espaciais (Brazil) and University of Washington
Biogeochemical Fluxes at the Ocean/Atmosphere Interface	Peter Brewer	Monterey Bay Aquarium Research Institute, California
Northern Biosphere Observation and Modeling Experiment	Josef Cihlar	Canada Centre for Remote Sensing
NCAR Project to Interface Modeling on Global and Regional Scales with EOS Observations	Robert Dickinson	National Center for Atmospheric Research, Colorado
Hydrology, Hydrochemical Modeling, and Remote Sensing in Seasonally Snow-Covered Alpine Drainage Basins	Jeff Dozier	University of California, Santa Barbara
Use of a Cryospheric System (CRYSYS) to Monitor Global Change in Canada	Barry Goodison	Canadian Atmospheric Environment Service
Observational and Modeling Studies of Radiative, Chemical, and Dynamical Interactions in the Earth's Atmosphere	William Grose	NASA/Langley Research Center, Virginia
Interannual Variability of the Global Carbon, Energy, and Hydrologic Cycles	James Hansen	NASA/Goddard Institute for Space Studies, New York
Interdisciplinary Studies of the Relationships between Climate, Ocean Circulation, Biological Processes, and Renewable Marine Resources	Graham Harris	Commonwealth Scientific and Industrial Research Organization (Australia)
Climate Processes Over the Oceans	Dennis Hartmann	University of Washington
Climate, Erosion, and Tectonics in the Andes and Other Mountain Systems	Bryan Isacks	Cornell University, New York
The Hydrologic Cycle and Climatic Processes in Arid and Semi-Arid Lands	Yann Kerr and Soroosh Sorooshian	Laboratoire d'Etudes et de Recherches en Teledetection Spatiale (France) and University of Arizona

EOS Interdisciplinary Science Investigations	Principal Investigators	Home Institutions
Global Hydrologic Processes and Climate	William Lau	NASA/Goddard Space Flight Center, Maryland
The Processing, Evaluation, and Impact on Numerical Weather Prediction of AIRS, AMSU, MODIS, and LAWS Data in the Tropics and Southern Hemisphere	John LeMarshall	Bureau of Meteorology Research Centre (Australia)
The Role of Air-Sea Exchanges and Ocean Circulation in Climate Variability	W. Timothy Liu	NASA/Jet Propulsion Laboratory, California
Changes in Biogeochemical Cycles	Berrien Moore III	University of New Hampshire
A Global Assessment of Active Volcanism, Volcanic Hazards, and Volcanic Inputs to the Atmosphere from EOS	Peter Mouginis-Mark	University of Hawaii
Investigation of the Atmosphere-Ocean-Land System Related to Climatic Processes	Masato Murakami	Meteorological Research Institute (Japan)
Chemical, Dynamical, and Radiative Interactions through the Middle Atmosphere and Thermosphere	John Pyle	University of Cambridge (United Kingdom)
The Development and Use of a Four-Dimensional Atmospheric-Ocean-Land Data Assimilation System for EOS	Richard Rood	NASA/Goddard Space Flight Center, Maryland
Polar Exchange at the Sea Surface (POLES): The Interaction of Oceans, Ice, and Atmosphere	Drew Rothrock	University of Washington
Using Multi-Sensor Data to Model Factors Limiting Carbon Balance in Global Grasslands	David Schimel	Colorado State University
Investigation of the Chemical and Dynamical Changes in the Stratosphere Up to and during the EOS Observing Period	Mark Schoeberl	NASA/Goddard Space Flight Center, Maryland
Biosphere-Atmosphere Interactions	Piers Sellers	NASA Goddard Space Flight Center, Maryland
Middle and High Latitudes Oceanic Variability Study	Meric Srokosz	James Rennell Centre for Ocean Circulation (UK)
Earth System Dynamics: The Determination and Interpretation of the Global Angular Momentum Budget Using EOS	Byron Tapley	University of Texas
An Interdisciplinary Investigation of Clouds and Earth's Radiant Energy System: Analysis	Bruce Wielicki	NASA/Langley Research Center, Virginia